EEC 4230 Mobile Communication Systems
Tutorial #1

Problem 1

Prove that for a hexagonal geometry, the co-channel reuse ratio is given by $Q = \sqrt{3N}$, where $N = i^2 + ij + j^2$. Hint: Use the cosine law and the hexagonal cell geometry.

Problem 2

Show that the frequency reuse factor for a cellular system is given by k/S, where k is the average number of channels per cell and S is the total number of channels available to the cellular service provider.

Problem 3

If 20 MHz of total spectrum is allocated for a duplex wireless cellular system and each simplex channel has 25 kHz RF bandwidth, find:

(a) the number of duplex channels.

(b) the total number of channels per cell site, if $N = 4$ cell reuse is used.

Problem 4

A cellular service provider decides to use a digital TDMA scheme which can tolerate a signal-to-interference ratio of 15 dB in the worst case. Find the optimal value of N for (a) omnidirectional antennas, (b) 120° sectoring, and (c) 60° sectoring. Should sectoring be used? If so, which case (60° or 120°) should be used? (Assume a path loss exponent of $n = 4$ and consider trunking efficiency.)

Problem 5

Suppose that a mobile station is moving along a straight line between base stations BS_1 and BS_2, as shown in Figure **1** The distance between the base stations is $D = 2000$ m. For simplicity, assume small scale fading is neglected and the received power (in dBm) at base station i, from the mobile station, is modeled as a function of distance on the reverse link

$$P_{r,i}(d_i) = P_0 - 10n\log_{10}(d_i/d_0) \quad \text{(dBm)} \quad i = 1,2$$

where d_i is the distance between the mobile and the base station i, in meters. P_0 is the received power at distance d_0 from the mobile antenna. Assume that $P_0 = 0$ dBm and $d_0 = 1$ m. Let n denote the path loss which is assumed to be equal to 2.9.

Assume the minimum usable signal level for acceptable voice quality at the base station receiver is $P_{r,min} = -88$ dBm, and the threshold level used by the switch for handoff initiation is $P_{r,HO}$. Consider that the mobile is currently connected to BS_1 and is moving toward a handoff (time required to complete a handoff, once that received signal level reaches the handoff threshold $P_{r,HO}$ is $\Delta t = 4.5$ seconds).

(a) Determine the minimum required margin $\Delta = P_{r,HO} - P_{r,min}$ to assure that calls are not lost due to weak signal condition during handoff. Assume that the base station antenna heights are negligible compared to the distance between the mobile and the base stations.

(b) Describe the effects of the margin $\Delta = P_{r,HO} - P_{r,min}$ on the performance of cellular systems.

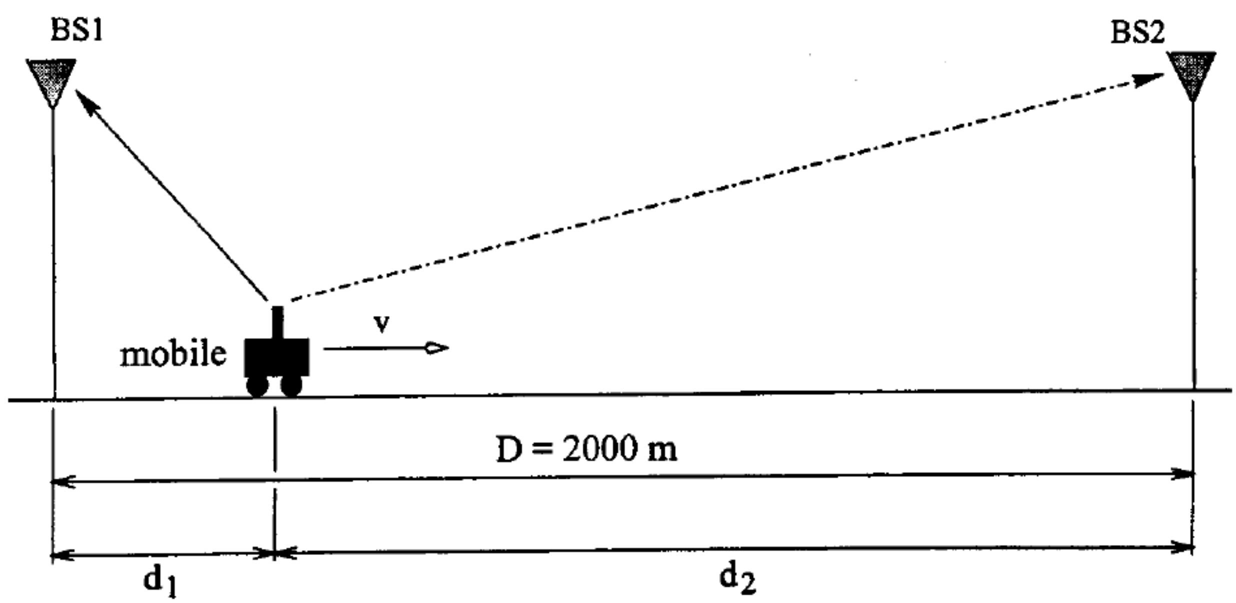

Figure 1: Cellular System with Two base stations

Problem 6

If an intensive propagation measurement campaign showed that the mobile radio channel provided a propagation path loss exponent of $n = 3$ instead of four, how would your design decisions in Problem **4** change? What is the optimal value of N for the case of $n = 3$?

Problem 7

A total of 24 MHz of bandwidth is allocated to a particular FDD cellular telephone system that uses two 30 kHz simplex channels to provide full duplex voice and control channels. Assume each cell phone user generates 0.1 Erlangs of traffic. Assume Erlang B is used.

(a) Find the number of channels in each cell for a four-cell reuse system.

(b) If each cell is to offer capacity that is 90% of perfect scheduling, find the maximum number of users that can be supported per cell where omnidirectional antennas are used at each base station.

(c) What is the blocking probability of the system in (b) when the maximum number of users are available in the user pool?

(d) If each new cell now uses 120° sectoring instead of omnidirectional for each base station, what is the new total number of users that can be supported per cell for the same blocking probability as in (c)?

(e) If each cell covers five square kilometers, then how many subscribers could be supported in an urban market that is 50 km × 50 km for the case of omnidirectional base station antennas?

(f) If each cell covers five square kilometers, then how many subscribers could be supported in an urban market that is 50 km × 50 km for the case of 120° sectored antennas?

Problem 8

For a $N = 7$ system with a $Pr[Blocking] = 1\%$ and average call length of two minutes, find the traffic capacity loss due to trunking for 57 channels when going from omnidirectional antennas to 60° sectored antennas. (Assume that blocked calls are cleared and the average per user call rate is $\lambda = 1$ per hour.)

Problem 9

Assume that a cell named "Radio Knob" has 57 channels, each with an effective radiated power of 32 W and a cell radius of 10 km. The path loss is 40 dB per decade. The grade of service is established to be a probability of blocking of 5% (assuming blocked calls are cleared). Assume the average call length is two minutes, and each user averages two calls per hour. Further, assume the cell has just reached its maximum capacity and must be split into four new microcells to provide four times the capacity in the same area. (a) What is the current capacity of the "Radio Knob" cell? (b) What is the radius and transmit power of the new cells? (c) How many channels are needed in each of the new cells to maintain frequency reuse stability in the system? (d) If traffic is uniformly distributed, what is the new traffic carried by each new cell? Will the probability of blocking in these new cells be below 0.1% after the split? Assume 57 channels are used at the original base station and the split cells.

Problem 10

A certain area is covered by a cellular radio system with 84 cells and a cluster size N. 300 voice channels are available for the system. Users are uniformly distributed over the area covered by the cellular system, and the offered traffic per user is 0.04 Erlang. Assume that blocked calls are cleared and the designated blocking probability is $P_b = 1\%$.

(a) Determine the maximum carried traffic per cell if cluster size $N = 4$ is used. Repeat for cluster sizes $N = 7$ and 12.

(b) Determine the maximum number of users that can be served by the system for a blocking probability of 1% and cluster size $N = 4$. Repeat for cluster sizes $N = 7$ and 12.

Problem 11

Exercises in trunking (queueing) theory:

(a) What is the maximum system capacity (*total* and *per channel*) in Erlangs when providing a 2% blocking probability with four channels, with 20 channels, with 40 channels?

(b) How many users can be supported with 40 channels at 2% blocking? Assume $H = 105$ s, $\lambda = 1$ call/hour.

(c) Using the traffic intensity calculated in part (a), find the grade of service in a lost call delayed system for the case of delays being greater than 20 seconds. Assume that $H =$ 105 s, and determine the GOS for four channels, for 20 channels, for 40 channels.

(d) Comparing part (a) and part (c), does a lost call delayed system with a 20 second queue perform better than a system that clears blocked calls?

Problem 12

A receiver in an urban cellular radio system detects a 1 mW signal at $d = d_0 = 1$ meter from the transmitter. In order to mitigate co-channel interference effects, it is required that the signal received at any base station receiver from another base station transmitter which operates with the same channel must be below –100 dBm. A measurement team has determined that the average path loss exponent in the system is $n = 3$. Determine the major radius of each cell if a seven-cell reuse pattern is used. What is the major radius if a four-cell reuse pattern is used?

Problem 13

A cellular system using a cluster size of seven is described in Problem 12 It is operated with 660 channels, 30 of which are designated as setup (control) channels so that there are about 90 voice channels available per cell. If there is a potential user density of 9000 users/km^2 in the system, and each user makes an average of one call per hour and each call lasts 1 minute during peak hours, determine the probability that a user will experience a delay greater than 20 seconds if all calls are queued.

Problem 14

Determine the noise floor (in dBm) for mobile receivers which implement the following standards: (a) AMPS, (b) GSM, (c) USDC, (d) DECT, (e) IS-95, and (f) CT2. Assume all receivers have a noise figure of 10 dB.

Problem 15

If a base station provides a signal level of –90 dBm at the cell fringe, find the SNR for each of the mobile receivers described in Problem 14

Problem 16

Assume each user of a single base station mobile radio system averages three calls per hour, each call lasting an average of 5 minutes.

(a) What is the traffic intensity for each user?

(b) Find the number of users that could use the system with 1% blocking if only one channel is available.

(c) Find the number of users that could use the system with 1% blocking if five trunked channels are available.

(d) If the number of users you found in (c) is suddenly doubled, what is the new blocking probability of the five channel trunked mobile radio system? Would this be acceptable performance? Justify why or why not.

Problem 17

Pretend your company won a license to build a U.S. cellular system (the application cost for the license was only $500!). Your license is to cover 140 square km. Assume a base station costs $500,000 and a MTSO costs $1,500,000. An extra $500,000 is needed to advertise and start the business. You have convinced the bank to loan you $6 million, with the idea that in four years you will have earned $10 million in gross billing revenues, and will have paid off the loan.

(a) How many base stations (i.e., cell sites) will you be able to install for $6 million?

(b) Assuming the earth is flat and subscribers are uniformly distributed on the ground, what assumption can you make about the coverage area of each of your cell sites? What is the major radius of each of your cells, assuming a hexagonal mosaic?

(c) Assume that the average customer will pay $50 per month over a four year period. Assume that on the first day you turn your system on, you have a certain number of customers which remains fixed throughout the year. On the first day of each new year, the number of customers using your system doubles and then remains fixed for the rest of that year. What is the minimum number of customers you must have on the first day of service in order to have earned $10 million in gross billing revenues by the end of the 4th year of operation?

(d) For your answer in (c), how many users per square km are needed on the first day of service in order to reach the $10 million mark after the 4th year?

Best Wishes,
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